Inflation Forecast Targeting: Implementing and Monitoring Inflation Targets

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Abstract

Inflation targeting is shown to imply inflation *forecast* targeting: the central bank's inflation forecast becomes an explicit intermediate target. Inflation forecast targeting simplifies both implementation and monitoring of monetary policy. The weight on output stabilization determines how quickly the inflation forecast is adjusted towards the inflation target. Money growth or exchange rate targeting is generally inferior than inflation targeting and leads to higher inflation variability. Commitment to 'target rules' may be better than commitment to 'instrument rules'.

JEL classification: E42, E52, E58

1 Introduction

In recent years a number of countries (New Zealand, Canada, U.K., Sweden, Finland, Australia and Spain) have instituted explicit inflation targeting. An inflation-targeting regime has several characteristics. The crucial one is a quantitative inflation target, typically 2 per cent per year. In most cases there is also an explicit tolerance interval around the inflation target, typically ± 1 percentage point. Finally, there is no explicit intermediate target, such as a money growth target or an exchange rate target (except for Spain which, as a participant of ERM, also has an exchange rate target). As argued in Leiderman and Svensson (1995, Introduction) the last characteristic is not crucial; (temporary) intermediate targets are not inconsistent with an inflation target, as long as the inflation target has priority if a conflict arises.[1]

The purpose of this paper is to examine inflation targeting with regard to potential problems with its implementation by the monetary authority and its monitoring by the public and market agents. Inflation targeting has some obvious general advantages, and some potentially serious problems. The general advantages include focusing monetary policy directly on achieving the goal of low and stable inflation. With a specified quantitative target, it provides an ex post measurement of monetary policy performance, namely realized inflation relative to the inflation target. It also provides measurement of the credibility of monetary policy, in the form of measures of inflation expectations relative to the inflation target. Both these measurements simplify the evaluation of monetary policy and thereby the accountability of monetary policy is increased. By increasing accountability, inflation targeting may serve as a potential commitment mechanism, reduce or eliminate any inflation bias (for instance, due to the reasons examined in Barro and Gordon (1983)) and increase the likelihood of achieving and maintaining low and stable inflation, as well as anchoring and stabilizing inflation expectations.

More specifically, as demonstrated in Svensson (1996c), in a framework where discretionary monetary policy leads to an inflation bias (for instance due to an implicit employment target that exceeds the natural rate of employment, as in Barro and Gordon (1983)), a low inflation target may also reduce or even remove the inflation bias. In some cases it may lead to the same equilibria as the linear inflation contracts proposed by Walsh (1995b) and extended by Persson and Tabellini (1993), but be relatively easier to implement. Since a low inflation target need not distort the relative output/inflation variability, 'inflation-target conservative' goals (that is, with a lower inflation target) for the central bank may lead to better equilibria than Rogoff's (1985) 'weight conservative' goals for the central bank (that is, with a higher weight on inflation stabilization).

However, inflation targeting faces some potentially serious problems with regard to both its implementation and its monitoring. First, inflation targeting may be difficult to implement, for the simple reason that central banks have imperfect control over inflation. Current inflation is essentially predetermined by previous decisions and contracts, which means that central banks can only affect future inflation. 'Long and variable lags', and variable strength in the effect of monetary policy on future inflation make decisions on current instrument setting inherently difficult. Inflation is also affected by other factors

[1] See the papers in Leiderman and Svensson (1995) and Haldane (1995), as well as Amner and Freeman (1995) and McCallum (1995), for discussion of and details on inflation targeting.

than monetary policy, in particular disturbances that occur within the 'control lag' between the instrument change and the resulting effect on inflation. Second, the imperfect control over inflation makes monitoring and evaluation of monetary policy by the public inherently difficult. For instance, with a control lag of 1.5-2 years, it appears that current monetary policy cannot be evaluated until realized inflation has been observed 1.5-2 years later. However, that observed inflation is the result of several other factors than monetary policy, in particular disturbances that monetary policy cannot respond to due to the control lags. Thus, measuring monetary policy performance is not straightforward. A central bank may argue that a particular deviation of realized inflation from the inflation target is due to factors outside its control, and that it should hence not be held accountable for the deviation.

With implementation, monitoring and evaluation made more difficult, accountability improves less, and the potential commitment mechanism is correspondingly weakened. Sceptics and critics may argue that the merits of inflation targeting are highly dubious, and that less sophisticated money growth targeting or exchange rate targeting is a safer way to achieve low inflation.[2]

This paper argues that the potentially serious problems with implementing and monitoring inflation targeting have a simple but powerful solution. Inflation targeting implies inflation *forecast* targeting: The central bank's inflation forecast becomes an intermediate target.[3] Making this explicit simplifies both implementation and monitoring of monetary policy. The central bank's inflation forecast is indeed an ideal intermediate target: it is by definition the current variable that is most correlated with the goal, it is more controllable than the goal, and it can be made more observable than the goal. It can also be made very transparent, and may therefore facilitate the central bank's communication with the public, and the public's understanding of monetary policy. In (rare) special cases when either money growth targeting or exchange rate targeting is the optimal arrangement, inflation targeting will automatically imply that arrangement. Very sophisticated money growth targeting can be made equivalent to inflation targeting, but it is much less transparent, whereas simple money growth targeting is inefficient in that it provides more inflation variability than inflation targeting.[4]

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[2] Cf. von Hagen (1996).

[3] The idea that long lags imply that forecasts should be targeted rather than current values goes back at least to Hall (1985), and is further discussed with regard to nominal GDP targeting in Hall and Mankiw (1994). With regard to explicit inflation forecast targeting, see King (1994, p. 118): "The use of an inflation target does not mean that there is no intermediate target. Rather, the intermediate target is the expected level of inflation at some future date chosen to allow for the lag between changes in interest rates and the resulting changes in inflation. In practice, we use a forecasting horizon of two years." See also Bowen (1995, p. 57): "The most appropriate guide to monetary policy [under inflation targeting] is the best obtainable forecast of the probability distribution for inflation, over a time horizon defined by how long it takes for a change in monetary policy to affect inflation. Such a forecast must use information from a wide variety of sources. It can be thought of as an intermediate target: monetary policy is to be adjusted to maximize the probability forecast at the time of the policy adjustment—of inflation falling within the target range by the time the adjustment has taken effect."

Clark, Laxton and Rose (1995) emphasize the role of lags in monetary policy and compare, in a model with a non-linear Phillips curve, myopic and forward-looking decision rules.

[4] By the central bank's inflation forecast I mean the central bank's own 'structural' (model-based) forecast, the forecast based on its view and (not necessarily completely formal) model of the fundamental determinants of inflation and the transmission mechanism of monetary policy. In particular, the central bank must have a view on the relevant policy multiplier, how the inflation forecast is affected by the monetary policy instrument. Within a discussion of nominal GDP targeting, Hall and Mankiw (1994)

The role of output stabilization in inflation targeting is a contentious issue, cf. Fischer (1996) and King (1996b). This paper shows that the weight on output stabilization in the central bank's loss function is directly related to the rate at which inflation is adjusted towards the inflation target. With a zero weight on output stabilization, the central bank should set the instrument such that the inflation forecast for the control lag always equals the inflation target. With a positive weight, the inflation forecast should be adjusted gradually towards the inflation target, at a slower rate the larger the weight. With this intuitive result, the issue appears less contentious.

This paper emphasizes the distinction between 'target rules' for intermediate targets and 'instrument rules' for the instrument (the latter proposed by McCallum (1990) and Taylor (1993, 1996a,b)) and argues that target rules are more advantageous.

Section 2 of the paper discusses the implementation of inflation targeting and demonstrates, with the help of a very simple model, that inflation targeting implies inflation forecast targeting. Section 3 discusses public monitoring and evaluation of inflation targeting. Section 4 shows that the inflation forecast is indeed an ideal intermediate target. Section 5 discusses the relation of inflation targeting to money targeting. Section 6 examines the role of output stabilization. Sections 7 discusses the role of bands for inflation. Section 8 examines the distinction between target rules and instrument rules. Section 9 concludes. Appendices A and B contain some technical points.[5]

2 Implementing inflation targeting: Inflation forecast targeting

This section argues that the solution to the potential problem in implementing inflation targeting consists of making the central bank's inflation forecast an explicit intermediate target. Although this is a very straightforward result that hardly requires a model, I believe that it is best demonstrated with the help of a very simple model. Although the result can be demonstrated in a much more elaborate model with an explicit role for agents' expectations, it is sufficient to use a much simpler one in this case. The model nevertheless has some structural similarity to more elaborate models used by some central banks.[6]

Consider therefore the model

$$\pi_{t+1} = \pi_t + \alpha_1 y_t + \alpha_2 x_t + \epsilon_{t+1} \tag{2.1}$$

have argued that the central bank should target outside forecasters' consensus forecast (of nominal GDP) rather than its own structural forecast. Woodford (1994) has shown, however, that targeting other forecasters' forecasts is problematic, if these forecasters incorporate in their forecasting procedure the central bank's feedback rule from their forecasts. Instability, multiple equilibria, or even non-existence of equilibria may result. These problems are avoided if the central bank targets its own structural forecast.

[5] After the first version of the present paper was written, I received a copy of Haldane (1996), which independently expresses similar ideas together with examples from UK inflation targeting.

[6] I believe these issues on implementing and monitoring inflation targeting can be discussed without necessarily assuming the systematic discretionary inflation bias (due to 'time-consistency' problems) emphasized in the modern 'principal-agent' approach to central banking (for instance in the work by Barro and Gordon (1983), Rogoff (1985), Cukierman (1992), Walsh (1995b), Persson and Tabellini (1993) and Svensson (1996c)) and disputed in the 'traditional' approach (for instance in McCallum (1995) and Romer and Romer (1996b)); see Tabellini (1995) for discussion of these approaches. Therefore the model here does not include any source of discretionary inflation bias, although this can easily be added without affecting the results.

$$y_{t+1} = \beta_1 y_t - \beta_2 (i_t - \pi_t) + \beta_3 x_t + \eta_{t+1} \tag{2.2}$$

$$x_{t+1} = \gamma x_t + \theta_{t+1}, \tag{2.3}$$

where $\pi_t = p_t - p_{t-1}$ is the inflation (rate) in year t, p_t is the (log) price level, y_t is an endogenous variable ((log) output (relative to potential output), say), x_t is an exogenous variable, i_t is the monetary policy instrument (the repo rate, say), and ϵ_t, η_t and θ_t are i.i.d. shocks in year t that are not known in year $t-1$. The coefficients α_1 and β_2 are assumed to be positive; the other coefficients are assumed to be nonnegative; β_1 and γ in addition fulfill $\beta_1 < 1$, $\gamma < 1$. The change in inflation is increasing in lagged output and the lagged exogenous variable. Output is serially correlated, decreasing in the lagged (pseudo-)'real' repo rate, $i_t - \pi_t$, and increasing in the lagged exogenous variable. The long-run natural output level is normalized to equal zero. The repo rate affects output with a one-year lag, and hence inflation with a two-year lag, the control lag in the model. That the instrument affects inflation with a longer lag than it affects output is the crucial property of the model. It is consistent with results from a number of VAR-studies.[7]

Suppose monetary policy is conducted by a central bank with an inflation target π^* (say 2 per cent per year). Interpret inflation targeting as implying that the central bank's objective in period t is to choose a sequence of current and future repo rates $\{i_\tau\}_{\tau=t}^{\infty}$ so as to minimize

$$\mathrm{E}_t \sum_{\tau=t}^{\infty} \delta^{\tau-t} L(\pi_\tau), \tag{2.4}$$

where E_t denotes expectations conditional upon (the central bank's) information available in year t, the discount factor δ fulfills $0 < \delta < 1$, and the period loss function $L(\pi_\tau)$ is

$$L(\pi_\tau) = \frac{1}{2} (\pi_\tau - \pi^*)^2 . \tag{2.5}$$

That is, the central bank wishes to minimize the expected sum of discounted squared future deviations of inflation from the target.[8]

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[7] In this annual discrete-time model, the instrument i_t can be interpreted as a two-week repo rate that must be held constant throughout each year. Then i_t can alternatively be interpreted as a one-year interest rate that is controlled by the central bank. Then (2.2) is consistent with an aggregate demand equation where output depends on the real one-year interest rate $i_t - \mathrm{E}_t \pi_{t+1}$,

$$y_{t+1} = \tilde{\beta}_1 y_t - \tilde{\beta}_2 (i_t - \mathrm{E}_t \pi_{t+1}) + \tilde{\beta}_3 x_t + \epsilon_{t+1},$$

where the expected inflation rate by (2.1) fulfills

$$\mathrm{E}_t \pi_{t+1} = \pi_t + \alpha_1 y_t + \alpha_2 x_t,$$

and where

$$\beta_1 = \tilde{\beta}_1 + \alpha_1 \tilde{\beta}_2, \ \beta_2 = \tilde{\beta}_2 \text{ and } \beta_3 = \tilde{\beta}_3 + \alpha_2 \tilde{\beta}_2.$$

A more elaborate model would include a long real interest rate in the aggregate demand function and link the long nominal rate to the repo rate via the expectations hypothesis, for instance as in Fuhrer and Moore (1995).

With a more precise terminology, the model has a non-increasing-inflation output level equal to zero. Strictly speaking, cf. McCallum (1989), the model violates the natural-rate hypothesis (of no long-run effect on output or employment of any monetary policy), in that a steady increasing inflation rate permanently increases output. Such policies will never be optimal with the loss functions to be used in this paper. If such policies are attempted, the presumption is that the model would break down.

[8] Since the central bank does not have perfect control over inflation it is not meaningful to minimize

It is crucial here that inflation targeting is interpreted as implying a single goal; that the inflation rate is the only variable in the period loss function (2.5). Svensson (1996c) has argued that inflation targeting may in practice be interpreted by central banks as involving additional goals for output or employment. The consequences of an additional goal of output or employment stabilization are discussed in Section 6. There it is shown that some weight on output stabilization leads to a very intuitive modification of the results.

Since the repo rate affects inflation with a two-year lag, it is practical to express π_{t+2} in terms of year t variables and $t+1$ and $t+2$ disturbances:

$$\begin{aligned}\pi_{t+2} &= (\pi_t + \alpha_1 y_t + \alpha_2 x_t + \epsilon_{t+1}) + \alpha_1 \left[\beta_1 y_t - \beta_2 i_t + \beta_2 \pi_t + \beta_3 x_t + \eta_{t+1}\right] \\ &\quad + \alpha_2 (\gamma x_t + \theta_{t+1}) + \epsilon_{t+2} \\ &= a_1 \pi_t + a_2 y_t + a_3 x_t - a_4 i_t + (\epsilon_{t+1} + \alpha_1 \eta_{t+1} + \alpha_2 \theta_{t+1} + \epsilon_{t+2}), \qquad (2.6)\end{aligned}$$

where

$$a_1 = 1 + \alpha_1\beta_2,\ a_2 = \alpha_1 (1 + \beta_1),\ a_3 = \alpha_1\beta_3 + \alpha_2(1+\gamma) \text{ and } a_4 = \alpha_1\beta_2. \qquad (2.7)$$

Since in this simple case the repo rate in year t will not affect the inflation rate in year t and $t+1$, but only in year $t+2$, $t+3$, ..., and the repo rate in year $t+1$ will only affect the inflation rate in year $t+3$, $t+4$, ..., we realize that we can find the solution to the optimization problem by assigning the repo rate in year t to hit, on an expected basis, the inflation target for year $t+2$, the repo rate in year $t+1$ to the inflation target for year $t+3$, etc. Thus, the central bank can find the optimal repo rate in year t as the solution to the simple period-by-period problem

$$\min_{i_t} \mathrm{E}_t \delta^2 L(\pi_{t+2}) \qquad (2.8)$$

(see Appendix A for details).[9]

The first-order condition for minimizing (2.8) with respect to i_t is

$$\frac{\partial \mathrm{E}_t \delta^2 L(\pi_{t+2})}{\partial i_t} = \mathrm{E}_t \left[\delta^2 (\pi_{t+2} - \pi^*) \frac{\partial \pi_{t+2}}{\partial i_t}\right] = -\delta^2 a_4 \left(\pi_{t+2|t} - \pi^*\right) = 0,$$

where $\pi_{t+2|t}$ denotes $\mathrm{E}_t \pi_{t+2}$, and where I have used that by (2.6) $\frac{\partial \pi_{t+2}}{\partial i_t} = -a_4$. It follows that the first-order condition can be written

$$\pi_{t+2|t} = \pi^*. \qquad (2.9)$$

That is, the repo rate in year t should be set so that the forecast of the one-year 'forward' inflation rate from year $t+1$ to year $t+2$, conditional upon information available in year t, equals the inflation target. Although a more precise terminology for this forecast would be the one-to-two-year forecast, I shall for simplicity call it the *two-year* forecast.

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the *realized* squared deviations, only the *expected* squared deviations (conditional upon the information available when the repo rate is set).

[9] The two-year lag makes the result especially easy to represent. Svensson (1996b) discusses the case with a general distributed lag.

(It should not be confused with the forecast of the average inflation rate between year t and year $t+2$.) Thus, the two-year inflation forecast can be considered an explicit intermediate target.[10] [11]

It follows that the inflation targeting loss function (2.5) can be replaced by an intermediate loss function $L^i(\pi_{t+2|t})$, the inflation *forecast* targeting loss function

$$L^i(\pi_{t+2|t}) = \frac{1}{2}\left(\pi_{t+2|t} - \pi^*\right)^2. \tag{2.10}$$

Instead of minimizing the *expected* squared deviations of the *future* two-year inflation rate π_{t+2} from the inflation target as in (2.8), the central bank can minimize the squared deviation of the *current* two-year inflation forecast $\pi_{t+2|t}$ from the inflation target,

$$\min_{i_t} L^i\left(\pi_{t+2|t}\right). \tag{2.11}$$

Since the first-order condition is the same, (2.9), the same optimal repo rate results. This is of course a straightforward application of standard certainty-equivalence in linear-quadratic models.

The two-year inflation forecast by (2.6) depends on the current state of the economy, π_t, y_t, x_t, and the instrument i_t,

$$\pi_{t+2|t} = a_1\pi_t + a_2 y_t + a_3 x_t - a_4 i_t. \tag{2.12}$$

Setting this equal to the inflation target, (2.9), leads to the central bank's optimal reaction function,

$$\begin{aligned} i_t &= \frac{1}{a_4}\left(-\pi^* + a_1\pi_t + a_2 y_t + a_3 x_t\right) \\ &= \pi_t + b_1\left(\pi_t - \pi^*\right) + b_2 y_t + b_3 x_t, \end{aligned} \tag{2.13}$$

where I have used (2.7) and

$$b_1 = \frac{1}{\alpha_1\beta_2},\ b_2 = \frac{1+\beta_1}{\beta_2} \text{ and } b_3 = \frac{\alpha_1\beta_3 + \alpha_2(1+\gamma)}{\alpha_1\beta_2}. \tag{2.14}$$

This reaction function is of the same form as the Taylor rule (1993), except that it also depends on the exogenous variable (and that the coefficients generally differ from

[10] An alternative objective function for an inflation targeting regime is to maximize the probability that future inflation falls within a symmetric band around the inflation target. With a symmetric probability distribution for future inflation, which is the case in the model used here, this results in the same intermediate target (2.9).

[11] Brunner and Meltzer (1967, p. 195) define an ideal indicator (that provides "the most reliable measure of the effect of monetary policy") as the differential (or logarithmic differential) of a social utility function (or a scalar variable monotonically related to the social utility) with respect to the monetary policy instrument. As emphasized by Brunner and Meltzer, both a utility function and a theory of the transmission mechanism is needed for the construction of an ideal indicator. In their framework with output as the goal of monetary policy and a velocity equation as the aggregate demand equation, the sum of the relative change of the adjusted monetary base and relative change of the money multiplier appears as an ideal indicator. In this framework with a specific loss function, Phillips curve, and aggregated demand function, an ideal Brunner-Meltzer indicator appears to be $-\frac{\partial \mathrm{E}_t L(\pi_{t+2})/\partial i_t}{\mathrm{E}_t L(\pi_{t+2})}\frac{di_t}{i_t} = -\frac{(\pi_{t+2|t}-\pi^*)\partial\pi_{t+2|t}/\partial i_t}{\mathrm{E}_t L(\pi_{t+2})}\frac{di_t}{i_t}$. Brunner and Meltzer do not consider explicit lags in the transmission mechanism, nor do they consider explicit inflation targeting.

0.5). The real repo rate $i_t - \pi_t$ is increasing in the excess of current inflation over the inflation target, in current output, and in the current exogenous variable. The instrument depends on current inflation, not because current inflation is targeted (current inflation is predetermined) but because current inflation together with output and the exogenous variable predict future inflation.[12]

With this reaction function the two-year inflation forecast will equal the inflation target, for all values of π_t, y_t and x_t. If the inflation forecast exceeds (falls short of) the inflation target, the repo rate should be increased (decreased) until the inflation forecast equals the target. If the current inflation rate increases, output increases, or the exogenous variable increases, the repo rate should be increased, in order to keep the inflation forecast equal to the inflation target.

Actual inflation in year $t+2$ will in equilibrium be

$$\begin{aligned} \pi_{t+2} &= \pi_{t+2|t} + \epsilon_{t+1} + \alpha_1\eta_{t+1} + \alpha_2\theta_{t+1} + \epsilon_{t+2} \\ &= \pi^* + \epsilon_{t+1} + \alpha_1\eta_{t+1} + \alpha_2\theta_{t+1} + \epsilon_{t+2}. \end{aligned} \tag{2.15}$$

It will deviate from the inflation target and the two-year inflation forecast by the forecast error,

$$\pi_{t+2} - \pi_{t+2|t} = \epsilon_{t+1} + \alpha_1\eta_{t+1} + \alpha_2\theta_{t+1} + \epsilon_{t+2}, \tag{2.16}$$

due to the disturbances that occur within the control lag, after the central bank has set the instrument.

Clearly the central bank cannot prevent deviations from the inflation target caused by disturbances occurring within the control lag. At best it can only control the deviations of the two-year forecast from the target. It can therefore be argued that the central bank should be held accountable for the forecast deviations from the target rather than the realized inflation deviations, if the forecast deviations can be observed.

Equilibrium output will by (2.1), (2.3) and (2.15) be given by

$$\begin{aligned} y_{t+1} &= \frac{\pi_{t+2} - \pi_{t+1} - \alpha_2 x_{t+1} - \epsilon_{t+2}}{\alpha_1} \\ &= \frac{\epsilon_{t+1} + \alpha_1\eta_{t+1} + \alpha_2\theta_{t+1} + \epsilon_{t+2}}{\alpha_1} \\ &\quad - \frac{\epsilon_t + \alpha_1\eta_t + \alpha_2\theta_t + \alpha_2(\gamma x_t + \theta_{t+1}) + \epsilon_{t+1} + \epsilon_{t+2}}{\alpha_1} \\ &= -\frac{\alpha_2}{\alpha_1}\gamma x_t - \frac{1}{\alpha_1}\epsilon_t - \eta_t - \frac{\alpha_2}{\alpha_1}\theta_t + \eta_{t+1}. \end{aligned} \tag{2.17}$$

To generalize from this example, inflation targeting implies a simple rule for its implementation. The central bank's inflation forecast for the horizon corresponding to the control lag (2 years in the example) becomes an intermediate target, and the instrument should hence be set so as to make the inflation forecast equal to the inflation target. Thus, if the inflation forecast is above (below) the target, the repo rate should be increased (decreased). This simple rule results in the optimal reaction function for the central bank.

[12] See Broadbent (1996) for an insightful discussion of Taylor rules in relation to inflation targeting. See also the comment Svensson (1996a) on Taylor (1996a).

Since the inflation forecast depends on all relevant information, the instrument will be a function of all relevant information.

Adjusting the instrument so the inflation forecast equals the target is the best the central bank can do. Ex post inflation will differ from the target, because of forecast and control errors, for instance due to disturbances that occur within the control lag. If the central bank is competent, the mean forecast errors will be zero, and the variance of the forecast errors minimized. Ideally, if the inflation forecast could be verified, the central bank should be accountable for deviations of the inflation forecast from the target, but not for the unavoidable deviations of realized inflation from the target. This issue is discussed further in Section7.

The central bank's inflation forecast will in practice have to combine both formal and informal components, for instance with judgemental adjustments of more formal structural forecasts. Forecasts will hardly ever be purely mechanical. This view is supported by the results of Cecchetti (1995), who has examined mechanical reduced-form inflation forecasts for the United States, with rather negative results. Forecast errors are sizeable, and there are frequent structural shifts in the forecast equations. However, forecast errors for one-year inflation rates, for instance for the one-to-two-year inflation rate emphasized in the model used here, are smaller than for one-quarter inflation rates. As emphasized by Kohn (1995), more structural modeling and use of extramodel information and judgment by forecasters are likely to produce forecasts with acceptable precision. In addition, forecasting inflation is likely to be easier in a situation when the central bank actively pursues inflation targeting and, importantly, the public expects the central bank to pursue inflation targeting so that inflation expectations are stabilized.

3 Monitoring inflation targeting

In the model used above, there is no specific need to monitor monetary policy in order to ensure that the central bank implements inflation targeting. If the central bank has the preferences described by (2.4) and (2.5), it will behave according to the optimal reaction function (2.13) with or without monitoring by outsiders. Let me now consider a simple modification of the setup which results in a need for outside monitoring.

Consider the inflation target π^* in (2.5) as the 'official' *explicit* inflation target, assigned to the central bank by society. Suppose, however, that the central bank has its own *implicit* inflation target that may deviate from the one assigned by society. More specifically, assume that the central bank has an intertemporal loss function of the form (2.4) with the same discount factor δ but a time-varying period loss function $L_t^b(\pi_t)$ given by

$$L_t^b(\pi_t) = \frac{1}{2}\left(\pi_t - \pi_t^b\right)^2 \tag{3.1}$$

$$\pi_t^b = \pi^* + z_t \tag{3.2}$$

$$z_{t+1} = (1-\rho)\bar{z} + \rho z_t + \xi_{t+1}, \tag{3.3}$$

where the central bank's implicit inflation target π_t^b deviates from the explicit one, the deviation z_t follows an AR(1) process, the unconditional mean $\bar{z}$ is constant, $|\rho| < 1$ and ξ_t is i.i.d. A positive unconditional mean $\bar{z}$ may be interpreted as representing a Barro-Gordon (1983) discretionary inflation bias.

The central bank's decision problem then becomes

$$\min_{i_t} \mathrm{E}_t \delta^2 L^b_{t+2}(\pi_{t+2}). \tag{3.4}$$

The first-order condition is

$$\frac{\partial \mathrm{E}_t \delta^2 L^b_{t+2}(\pi_{t+2})}{\partial i_t} = -\delta^2 a_4 \left(\pi_{t+2|t} - \pi^* - z_{t+2|t}\right) = -\delta^2 a_4 \left[\pi_{t+2|t} - \pi^* - (1-\rho^2)\bar{z} - \rho^2 z_t\right] = 0.$$

Thus, the first-order condition can be written

$$\pi_{t+2|t} = \pi^* + (1-\rho^2)\bar{z} + \rho^2 z_t. \tag{3.5}$$

The corresponding reaction function will be

$$i_t = \pi_t + b_1 \left[\pi_t - \pi^* - (1-\rho^2)\bar{z} - \rho^2 z_t\right] + b_2 y_t + b_3 x_t. \tag{3.6}$$

where the b coefficients are given by (2.14).

Equilibrium inflation in year $t+2$ will be

$$\pi_{t+2} = \pi^* + (1-\rho^2)\bar{z} + \rho^2 z_t + \epsilon_{t+1} + \alpha_1 \eta_{t+1} + \alpha_2 \theta_{t+1} + \epsilon_{t+2}, \tag{3.7}$$

and equilibrium output will fulfill

$$\begin{aligned} y_{t+1} &= \frac{\pi_{t+2} - \pi_{t+1} - \alpha_2 x_{t+1} - \epsilon_{t+2}}{\alpha_1} \\ &= \rho^2(z_t - z_{t-1}) - \frac{\alpha_2}{\alpha_1}\gamma x_t - \frac{1}{\alpha_1}\epsilon_t - \eta_t - \frac{\alpha_2}{\alpha_1}\theta_t + \eta_{t+1}. \end{aligned} \tag{3.8}$$

Thus, if the central bank's implicit inflation target deviates from the explicit one by z_t in year t, the central bank will choose the repo rate so as to set its two-year inflation forecast above the explicit inflation target by $(1-\rho^2)\bar{z} + \rho^2 z_t$, the expected $t+2$ inflation target deviation. Compared to the situation when the central bank shares society's inflation target, the equilibrium inflation in year $t+2$ will deviate by that same amount, and for given π_t, y_t and x_t, the repo rate in year t will be lower by $b_1\left[(1-\rho^2)\bar{z} + \rho^2 z_t\right]$.

Can public monitoring of the central bank prevent these deviations? Suppose the public cannot directly observe the central bank's implicit inflation target π^b_t, so that the latter is private information to the central bank. Assume in the simplest case that the public has the same information about the model (2.1)-(2.3) as the central bank, and that the public observes π_t, y_t, x_t and i_t in year t (and hence can extract the disturbances ϵ_t, η_t and θ_t). Even though the public does not directly observe the central bank's inflation target π^b_t, it can infer the relevant deviation $(1-\rho^2)\bar{z} + \rho^2 z_t$, either from comparing the current instrument with that corresponding to the optimal reaction function (2.13), or by using (2.12) to form an inflation forecast $\pi_{t+2|t}$ and observe its deviation from the explicit inflation target. (Note that the public need not know the stochastic process (3.3) for the central bank's deviations from the inflation target.)[13]

[13] Cf. Cukierman and Meltzer (1986) and Faust and Svensson (1996) for analysis of situations when the central bank preferences cannot be perfectly inferred but instead are estimated by the public with a Kalman filter.

Thus, the public can spot deviations of the inflation forecast from the explicit inflation target, and by criticizing the central bank for such deviations reduce or even eliminate such deviations (assuming the public agrees with the official inflation target). More specifically, consider such public criticism as equivalent to giving the central bank an additional loss in year t equal to

$$\varphi L_t^i(\pi_{t+2|t}),$$

where $L^i(\pi_{t+2|t})$ is given by (2.10) and the parameter $\varphi > 0$ measures the intensity of the criticism. Consider further the central bank's behavior in the face of such monitoring as minimizing in year t the total loss

$$\mathrm{E}_t \delta^2 L_{t+2}^b(\pi_{t+2}) + \varphi L^i(\pi_{t+2|t}).$$

The first-order condition with respect to i_t will be

$$\delta^2 \left[\pi_{t+2|t} - \pi^* - (1-\rho^2)\bar{z} - \rho^2 z_t\right] + \varphi\left(\pi_{t+2|t} - \pi^*\right) = 0,$$

hence

$$\pi_{t+2|t} = \pi^* + \frac{(1-\rho^2)\bar{z} + \rho^2 z_t}{1 + \varphi/\delta^2}.$$

By intensive criticism, that is, a large φ, the public can enforce that the central bank's inflation forecast is close to the explicit inflation target.[14]

In the real world, how can the public monitor and evaluate monetary policy with an inflation target? How can the central bank's inflation forecast become observable to the public, so the public can detect deviations from the explicit inflation target? The best way to make the central bank's inflation forecast observable to the public and to allow the most thorough monitoring of monetary policy, I believe, is for the central bank to reveal the details of its forecast to the public. This involves revealing the central bank's model, information, assumptions, and judgments in order to allow public scrutiny and discussion of these, including comparison with outsiders' forecasts and analysis. In terms of the model used above, this involves revealing the model (2.1)-(2.3) and its coefficients to the public, as well as the central bank's information about the current state of the economy. Full revelation and public scrutiny is likely to provide the best incentive for high-quality analysis and forecasting by the central bank and to minimize the risk of self-serving bias in the central bank's forecast. An example of this is the increasing occurrence, and increasing quality, of *Inflation Reports* by inflation targeting central banks, although a fair amount of detail in analysis and assumptions is still kept secret.[15]

Central banks have a strong tradition of secrecy (mostly for no good reasons, I believe).[16] If an inflation targeting central bank keeps essential components of its inflation

[14] This construction can be interpreted as an inflation contract along the lines of Walsh (1995b) and Persson and Tabellini (1993), where the central bank suffers a cost $\varphi L^i\left(\pi_{t+2|t}\right)$ that depends on the inflation forecast.

[15] To the extent that the central bank has objectives that deviate from the official ones, it may have an incentive to misrepresent its model and information (in addition to its objectives). The central bank's incentives to misrepresent the truth and mechanism design to ensure truth-telling is an increasingly relevant subject for future research. See Persson and Tabellini (1993) and Walsh (1995a) for examples of incentive schemes that induce the central bank to reveal the truth.

[16] See Goodfriend (1986) for a classic discussion of secrecy and central banking, and see King (1994) and Haldane (1996) for the role of transparency in UK inflation targeting.

forecast secret and thus prevents public observation and scrutiny, there are still ample opportunities to monitor the inflation targeting. Sophisticated observers of monetary policy can, and certainly will, publish their own inflation forecasts and scrutinize monetary policy with the help of these. Less sophisticated observers can always obtain publicly available inflation forecasts by reputable forecasters, for instance in the convenient form of "Consensus Forecasts" already made available by specialized publishers. Such forecasts are frequently published and updated with new information, allowing continuous observation of outsiders' inflation forecasts, even if the central bank is secretive about its forecast.

Central banks can be legally obliged to provide information to the public. It is also possible for governments to create an independent body, separate from the central bank, that monitors monetary policy. This may be a possibility that has received insufficient attention in discussions of central bank reform.

Thus, outsiders have ample opportunities to monitor and evaluate the central bank's policy, either with the central bank's own analysis and forecast available, or with that of outside forecasters and analysts. In its simplest form, monitoring inflation targeting then consists of observing whether available inflation forecasts are on target or whether they systematically exceed or fall short of the target, in which case the direction (although not the magnitude) of the warranted correction of monetary policy is obvious, since the principles of inflation targeting monetary policy are so simple and transparent.

In most situations the central bank and sophisticated outside observers are likely to have approximately the same information about the state of the economy and approximately similar models. There is no reason for systematic biases in information or models between the central bank and these sophisticated observers.[17] From this point of view, the example above may be rather realistic. The central bank has a distinct information advantage, though, with regard to the planned future path for the instrument, especially if this is related to implicit monetary policy goals that deviate from the official ones. The current instrument setting is observable to the public, but the central bank's plan for future instrument levels is not. Inflation forecasts for longer horizons than the control lag (that is, horizons longer than two years in the example above) will be contingent on expected future instrument settings. This means that there could be systematic differences between the central bank's and outsiders inflation forecasts for longer horizons, depending upon differences between the instrument plan of the central bank and the instrument expectations of the outsiders. For instance, if the central bank's longer term inflation forecast is below outsiders' forecasts, this should correspond to a situation when the central bank plans a less expansionary monetary policy than expected by the outsiders, which in turn should correspond to the central bank having a lower implicit inflation target than the public believes.

The public's consensus expectations about the future repo rate can be inferred from the

[17] For support of this view from inside Bank of England, see Briault, Haldane and King (1995). Romer and Romer (1996a), comparing forecast errors of the Federal Reserve and of commercial forecasters, report evidence of an informational advantage of the Federal Reserve, but argue that the most likely explanation for any such advantage is not data availability itself but rather that its staff is better at processing and interpreting information, which is consistent with the fact that Federal Reserve Board commits far more resources to forecasting than even the largest commercial forecasters. Whether the relative commitment of resources to forecasting is the same in other countries is an open question.

implicit forward interest rate curve that can be estimated from money-market yield curves or directly observed on the futures interest rate market (with due account of possible risk premia).[18] Thus, the central bank can compare its repo rate plan to the forward rate curve for systematic discrepancies. Such discrepancies, along with corresponding discrepancies in inflation forecast, are a symptom of credibility problems, in the sense that the implicit goals of the central bank deviate from the public's estimate of these goals. One possible remedy to such credibility problems is increased revelation of central bank plans and analysis. If the public's expectations about the future repo rate coincide with the central bank's plan for the instrument, but the public's inflation forecasts differ from the central bank's, this is an indication of differences in models or information between the public and the bank. Increased revelation by the central bank about its models and information may also remedy that situation.

Ideally, the central bank's implicit goals coincide with the explicit inflation target, and the public understands the central bank's implicit reaction function and has similar models and information as the bank. Then the bank's instrument plan would be consistent with the forward rate curve and the public's and the bank's inflation forecasts should be similar and equal to the explicit inflation target, both for the horizon corresponding to the control lag and for longer horizons.

More sophisticated evaluation of monetary policy would examine and compare the ex post forecast errors of the central bank and outside forecasts with respect to bias and variance. This requires more than the current few years of data from the inflation targeting regimes, though.

The transparency of inflation forecast targeting might help improve the sometimes deficient state of current monetary policy debate in the media in inflation targeting countries (the debate for instance frequently includes requests for lower interest rates without reference to inflation forecasts, sometimes when inflation forecasts clearly exceed targets, cf. the discussion in King (1996a)). Perhaps it would then be more natural for debaters to specify whether they share or have different targets, forecasts, estimates of instrument effects and control lags, etc.

4 An ideal intermediate target

A good intermediate target for monetary policy is highly correlated with the goal, easier to control by the central bank than the goal, easier to observe by both the central bank and the public than the goal, and transparent so that central bank communication with the public and public understanding and prediction of monetary policy is facilitated (cf. Brunner and Meltzer (1967), Friedman (1990) and McCallum (1990)). From this perspective, the central bank's inflation forecast appears to be an ideal intermediate target.

First, the inflation forecast $\pi_{t+2|t}$ is by definition the year t variable that has the *highest correlation* with $t+2$ inflation, since it minimizes the variance of forecast errors and by (2.12) uses all the relevant information in π_t, y_t and x_t, rather than an arbitrary subset of the available information.

[18] See for instance Svensson (1994), Söderlind and Svensson (1996) and various issues of Bank of England's *Inflation Report* for discussion and interpretation of yield curves for monetary policy purposes.

Second, by definition the inflation forecast $\pi_{t+2|t}$ is *more controllable* than inflation π_{t+2} itself. The effect of the instrument on the inflation forecast is the same as the effect on mean inflation, and the variance of the inflation forecast is less than that of inflation, since the forecast errors (2.16) are subtracted.

Third, the inflation forecast is *easier to observe* by the central bank than inflation. The forecast $\pi_{t+1|2}$ is (continuously) observable by the central bank in year t, since it depends on year t information; it is not necessary to wait until year $t+2$ to observe realized inflation. Also, realized inflation is affected by additional disturbances. As argued in Section 3, the inflation forecast can also be made observable by the public, either because the central bank reveals its forecast to the public, or because outside forecasters' inflation forecasts are easily accessible. This facilitates outside monitoring of the central bank.

Fourth, inflation forecast targeting is very *transparent*. Although the construction of the forecast is difficult and resource-demanding, the monetary policy conclusions from a given inflation forecast are straightforward: If the forecast is above (below) the target, monetary policy should be adjusted in a contractionary (expansionary) direction. If the forecast is on target, monetary policy is appropriate. I cannot imagine simpler principles, and I cannot imagine anything easier to explain to the public, or anything more conducive to public understanding of monetary policy.

Inflation forecast targeting also has straightforward implications for how to predict monetary policy. Predicting monetary policy becomes equivalent to predicting future inflation, which implies that the information relevant for predicting monetary policy is precisely the information relevant to predicting inflation.

The transparency of inflation forecast targeting is also likely to focus and motivate the work inside the central bank. It is likely to provide strong incentives to improve the central bank's understanding and structural models of the economy, especially if the central bank chooses or is required to make its model, analysis and forecast public. It helps to clarify for what the central bank can, and cannot, be accountable.

5 Money growth targeting

Inflation forecast targeting generally uses all relevant information for predicting future inflation. This information may include some measure of the money stock, but normally also other macro variables. In the (rare) special case when future inflation is best predicted by just the growth rate of some money aggregate, that is, money growth is a sufficient statistic for future inflation, inflation forecast targeting will be equivalent to money growth targeting. Similarly, if future inflation for a small open economy is best predicted only by the rate of exchange rate depreciation, inflation targeting will be equivalent to exchange rate (depreciation) targeting. But normally money growth or exchange rate depreciation are not sufficient statistics for future inflation; that is, other information has additional predictive value. Then money growth targeting or exchange rate targeting is inefficient and leads to a worse outcome than inflation forecast targeting.[19]

To illustrate this within the above model, add the following money demand function:

$$m_{t+1} - p_{t+1} = y_{t+1} - \kappa i_t + \nu_{t+1}, \tag{5.1}$$

[19] See Friedman (1990, 1995) for a more general discussion of money growth targeting.

where m_t is (the log of) some monetary aggregate (M3, say), the income velocity for simplicity is unity, the coefficient κ is positive, the repo rate affects money demand with a lag, and ν_{t+1} is an i.i.d. disturbance.

This formulation takes into account the fact that the monetary aggregate cannot be an instrument of the central bank, in the sense that the central bank does not have perfect control of it. The broader the aggregate, the less control has the central bank. It can even be disputed that such a narrow an aggregate as the monetary base is under complete control of the central bank, cf. Goodhart (1994). In (5.1) above, the central bank can affect the monetary aggregate by affecting the money demand, via the direct lagged effect on money demand of the instrument, the repo rate, and via the indirect effect of the instrument on aggregate demand for output. The supply of money then adjusts to money demand by endogenous adjustment of the monetary base. (The price level in (5.1) is predetermined by (2.1).)

First-difference (5.1), which gives

$$\mu_{t+1} = \pi_{t+1} + y_{t+1} - y_t - \kappa i_t + \kappa i_{t-1} + \nu_{t+1} - \nu_t, \tag{5.2}$$

where $\mu_{t+1} = m_{t+1} - m_t$ denotes (the) money growth (rate).

Since the repo rate affects money growth with a one-year lag, rewrite μ_{t+1} in terms of year t variables and $t+1$ disturbances:

$$\begin{aligned}
\mu_{t+1} &= \pi_{t+1} + y_{t+1} - y_t - \kappa i_t + \kappa i_{t-1} + \nu_{t+1} - \nu_t \\
&= (\pi_t + \alpha_1 y_t + \alpha_2 x_t + \epsilon_{t+1}) \\
&\quad + \left(\beta_1 y_t - \beta_2 i_t + \beta_2 \pi_t + \beta_3 x_t + \eta_{t+1}\right) - y_t - \kappa i_t + \kappa i_{t-1} + \nu_{t+1} - \nu_t \\
&= d_1 \pi_t + d_2 y_t + d_3 x_t - d_4 i_t + \kappa i_{t-1} - \nu_t + \left(\epsilon_{t+1} + \eta_{t+1} + \nu_{t+1}\right),
\end{aligned} \tag{5.3}$$

where

$$d_1 = 1 + \beta_2,\ d_2 = \alpha_1 + \beta_1 - 1,\ d_3 = \alpha_2 + \beta_3, \text{ and } d_4 = \beta_2 + \kappa. \tag{5.4}$$

The one-year money growth forecast is hence

$$\mu_{t+1|t} = d_1 \pi_t + d_2 y_t + d_3 x_t - d_4 i_t + \kappa i_{t-1} - \nu_t. \tag{5.5}$$

Eliminate i_t between (5.5) and (2.12), and express the two-year inflation forecast in terms of year t variables (aside from the repo rate) and the one-year money growth forecast,

$$\begin{aligned}
\pi_{t+2|t} &= a_1 \pi_t + a_2 y_t + a_3 x_t - \frac{a_4}{d_4}\left(-\mu_{t+1|t} + d_1 \pi_t + d_2 y_t + d_3 x_t + \kappa i_{t-1} - \nu_t\right) \\
&= f_1 \pi_t + f_2 y_t + f_3 x_t - f_4 i_{t-1} + f_5 \nu_t + f_5 \mu_{t+1|t},
\end{aligned} \tag{5.6}$$

where

$$f_1 = a_1 - \frac{a_4 d_1}{d_4},\ f_2 = a_2 - \frac{a_4 d_2}{d_4},\ f_3 = a_3 - \frac{a_4 d_3}{d_4},\ f_4 = \frac{a_4 \kappa}{d_4} \text{ and } f_5 = \frac{a_4}{d_4}. \tag{5.7}$$

Let $\mu^*_{t+1|t}$ denote the one-year money growth forecast that makes the two-year inflation forecast equal to the inflation target and hence fulfills,

$$\pi^* = f_1 \pi_t + f_2 y_t + f_3 x_t - f_4 i_{t-1} + f_5 \nu_t + f_5 \mu^*_{t+1|t}.$$

This results in

$$\begin{aligned}\mu^*_{t+1|t} &= \frac{1}{f_5}\left(\pi^* - f_1\pi_t - f_2 y_t - f_3 x_t + f_4 i_{t-1} - f_5\nu_t\right)\\ &= \pi^* - g_1\left(\pi_t - \pi^*\right) - g_2 y_t - g_3 x_t + \kappa(i_{t-1} - \pi^*) - \nu_t,\end{aligned} \tag{5.8}$$

where

$$g_1 = \frac{f_1}{f_5},\ g_2 = \frac{f_2}{f_5} \text{ and } g_3 = \frac{f_3}{f_5}. \tag{5.9}$$

It follows that we can interpret $\mu^*_{t+1|t}$ as a *conditional* one-year money growth target that depends on the information available in year t, in this case on π_t, y_t, x_t, i_{t-1} and ν_t. The repo rate i_t should then be chosen so as to minimize

$$\mathrm{E}_t\frac{1}{2}\left(\mu_{t+1} - \mu^*_{t+1|t}\right)^2$$

(subject to (5.3)), or, equivalently, chosen so as to fulfill the first-order condition that the one-year money growth forecast equals the money growth target,

$$\mu_{t+1|t} = \mu^*_{t+1|t}. \tag{5.10}$$

Fulfilling (5.10) will imply the reaction function (2.13) and is equivalent to fulfilling (2.9).

Note that money growth targeting implies money growth *forecast* targeting, for the simple reason that money growth reacts with a lag to the instrument and is imperfectly controlled.

We can also consider an *unconditional* money growth target, μ^*, that is constant over time. We realize from (5.2) and (5.8) that the unconditional money growth target must equal the inflation target,

$$\mu^* = \pi^*, \tag{5.11}$$

in order to cause average inflation to be equal to the target.

Suppose the repo rate is set so as to fulfill the unconditional money growth target,

$$\pi^* = \mu_{t+1|t} = d_1\pi_t + d_2 y_t + d_3 x_t - d_4 i_t + \kappa i_{t-1} - \nu_t.$$

This results in the reaction function

$$\begin{aligned} i_t &= \frac{1}{d_4}\left[-\pi^* + d_1\pi_t + d_2 y_t + d_3 x_t + \kappa i_{t-1} - \nu_t\right]\\ &= \pi_t + h_1(\pi_t - \pi^*) + h_2 y_t + h_3 x_t + h_4(i_{t-1} - \pi_t) - h_1\nu_t,\end{aligned} \tag{5.12}$$

where

$$h_1 = \frac{1}{\beta_2 + \kappa},\ h_2 = \frac{\alpha_1 + \beta_1 - 1}{\beta_2 + \kappa},\ h_3 = \frac{\alpha_2 + \beta_3}{\beta_2 + \kappa} \text{ and } h_4 = \frac{\kappa}{\beta_2 + \kappa}. \tag{5.13}$$

This reaction function should be compared with the optimal reaction function (2.13). It will result in a different equilibrium, with average inflation equal to π^*, but with more variability of inflation. Due to the persistence of both output and the exogenous variable, there will be persistent deviations of both realized inflation and conditional

inflation expectations from the inflation target. The equilibrium will be inefficient, since the intertemporal loss (2.5) will be higher.

Thus, although the sophisticated conditional money growth targeting (5.10) can achieve the same equilibrium as the optimal reaction function (2.13), it is less direct and less transparent. Its role is only to induce the correct reaction function (2.13). Unconditional money growth targeting (5.11) is perhaps more transparent than the conditional one. It will result in long-run average inflation equal to the target, but inflation and inflation expectations will be more variable and show persistent deviations from the target, and unconditional money growth targeting will hence be inefficient.[20]

Can unconditional money growth targeting ever be optimal? Consider the expression for the two-year inflation target as a function of the one-year money growth forecast and year t variables other than the repo rate, (5.6). Consider the special case when

$$f_1 = f_2 = f_3 = f_4 = 0,\ f_5 = 1 \text{ and } \nu_t = 0, \tag{5.14}$$

that is when money growth is a sufficient statistic for future inflation, and when there are no disturbances to money demand. Then unconditional money growth targeting would be optimal. The conditions (5.14) on the f-coefficients cannot be fulfilled in the model used here. Nevertheless, if they could be fulfilled (which requires some other transmission mechanism for monetary policy than assumed in the above model), inflation targeting would imply unconditional money growth targeting.

Generally, inflation targeting will imply some simple money growth targeting if and only if such money growth targeting is appropriate.

The previous discussion can be adapted to exchange rate targeting, with similar conclusions. Inflation targeting will automatically imply exchange rate targeting if, and only if, exchange rate targeting is optimal.[21]

6 Output stabilization

The above results are very straightforward when inflation targeting is interpreted as implying one goal only, in the sense that inflation is the only argument of the period loss function (2.5). If inflation targeting is interpreted as involving additional goals, as in Svensson (1996c), the situation will be somewhat more complicated. Generally, additional goals motivate temporary deviations of the inflation forecast from the inflation target.

[20] Bundesbank's money growth targets are formulated from a simple quantity equation relationship, such that the money growth target equals the sum of the implicit inflation target of 2 per cent, previously called 'unavoidable' inflation and now called 'normative' inflation, and the capacity growth forecast, less the forecast of the velocity trend (von Hagen (1995)). In terms of the model used here, both the capacity growth forecast and the velocity trend forecast are zero. Hence, Bundesbank's money growth target in this model corresponds to the unconditional μ^*. Thus, adherence to this money growth target would be inefficient. However, as emphasized for instance in von Hagen (1995, 1996) and Clarida and Gertler (1996), the Bundesbank has a most flexible approach to its money growth target, frequently deviating from the money growth target when the inflation forecast is consistent with the inflation target. This might be interpreted as a somewhat nontransparent attempt to adhere to the conditional money growth target (5.8).

[21] See Persson and Tabellini (1996) for a comparision of inflation targeting, money growth targeting and exchange rate targeting for 'ins' and 'outs' of the EMU.

Let me consider the case when there are additional stabilization goals with regard to real variables, like output or employment. More specifically, consider a situation when there is a long-run inflation target π^*, but no long-run output target (other than the natural rate of output), since monetary policy cannot affect output in the long run. In the short run, suppose the goal of monetary policy is to stabilize both inflation and output around the long-run inflation target and natural output rate, respectively. Thus, in the goals for monetary policy, there is a symmetry between inflation and output in the short run, but *not* in the long run. This situation can be described with a period loss function

$$L(\pi_t, y_t) = \frac{1}{2}\left[(\pi_t - \pi^*)^2 + \lambda y_t^2\right], \tag{6.1}$$

where $\lambda > 0$ is the relative weight on output stabilization. The intertemporal loss function is

$$\mathrm{E}_t \sum_{\tau=t}^{\infty} \delta^{\tau-t} L(\pi_\tau, y_\tau). \tag{6.2}$$

The case examined in previous sections corresponds to $\lambda = 0$.[22]

Simplify the model by eliminating the effect of the exogenous variable,[23] that is, set

$$\alpha_2 = \beta_3 = 0. \tag{6.3}$$

Then the model is

$$\pi_{t+1} = \pi_t + \alpha_1 y_t + \epsilon_{t+1} \tag{6.4}$$

$$y_{t+1} = \beta_1 y_t - \beta_2(i_t - \pi_t) + \eta_{t+1}. \tag{6.5}$$

In Appendix B, it is shown that the first-order condition for minimizing (6.2) over the repo rate can be written

$$\pi_{t+2|t} - \pi^* = -\frac{\lambda}{\delta\alpha_1 k} y_{t+1|t}, \tag{6.6}$$

where the coefficient $k \geq 1$ is given by

$$k = \frac{1}{2}\left(1 - \frac{\lambda(1-\delta)}{\delta\alpha_1^2} + \sqrt{\left(1 + \frac{\lambda(1-\delta)}{\delta\alpha_1^2}\right)^2 + \frac{4\lambda}{\alpha_1^2}}\right). \tag{6.7}$$

That is, the two-year inflation forecast should equal the inflation target only if the one-year output forecast equals the natural output rate. Otherwise it should exceed the inflation target in proportion to how much the one-year output forecast falls short of the natural

[22] Nominal income targeting can of course be examined in this framework. Note that the lag structure makes nominal income targeting a bit awkward and complex, though. Several possible definitions of (pseudo) nominal GDP, G_t, are conceivable, the one most convenient given the lag structure perhaps being $G_{t+2} = \pi_{t+2} + \frac{1}{2}y_{t+1}$, with the loss function $\mathrm{E}_t\frac{1}{2}\delta^2(G_{t+2} - G^*)$, where G^* is the nominal GDP target. Aside from problems with the lag structure, nominal GDP targeting, as always involves a arbitrary constant marginal rate of substitution between inflation (or the price level) and output. See, Svensson (1996b) for further comparision between inflation targeting and nominal GDP targeting.

[23] See Svensson (1996b) for discussion of the role of exogenous variables in inflation targeting with output stabilization.

output level. The proportionality coefficient, $\frac{\lambda}{\delta\alpha_1 k}$, is increasing in the relative weight on output stabilization, λ, and decreasing in the (short-run) inflation/output trade-off, α_1.

The first-order condition (6.6) can be rewritten in a way that has a more intuitive interpretation. Since by (6.4)

$$y_{t+1|t} = \frac{1}{\alpha_1}\left(\pi_{t+2|t} - \pi_{t+1|t}\right)$$

we can eliminate $y_{t+1|t}$ and get, after some algebra,

$$\pi_{t+2|t} = \pi^* + c\left(\pi_{t+1|t} - \pi^*\right), \tag{6.8}$$

where c is given by

$$c = \frac{\lambda}{\lambda + \delta\alpha_1^2 k} \tag{6.9}$$

and fulfills $0 \leq c < 1$. Thus, the two-year inflation forecast's deviation from the long-run inflation target should be a fraction of the one-year inflation forecast's deviation (note that the latter is predetermined). When $\lambda = 0$, $c = 0$ and the first-order condition collapses to (2.9).

Thus, when there is some weight on output stabilization, instead of adjusting the two-year inflation forecast all the way to the inflation target, the central bank should let it return gradually to the long-run inflation target. The intuition for this is that always adjusting the two-year inflation forecast all the way to the long-run inflation target, regardless of the one-year inflation forecast, requires more output fluctuations. If there is a positive weight on output stabilization, a gradual adjustment of the two-year inflation forecast towards the long-run inflation target reduces output fluctuations. The higher the weight on output stabilization, the slower the adjustment of the inflation forecast towards the long-run inflation target (the larger the coefficient c, see Appendix B).

Since the one-year output forecast and the two-year inflation forecast fulfill

$$\begin{aligned} y_{t+1|t} &= \beta_1 y_t - \beta_2\left(i_t - \pi_t\right) \\ \pi_{t+2|t} &= \pi_t + \alpha_1(1+\beta_1)y_t - \alpha_1\beta_2\left(i_t - \pi_t\right), \end{aligned}$$

it follows from (6.6) (see Appendix B) that the reaction function can be written

$$\begin{aligned} i_t &= \pi_t + \frac{\delta\alpha_1 k}{\beta_2\lambda}\left(\pi_{t+2|t} - \pi^*\right) + \frac{\beta_1}{\beta_2}y_t \qquad (6.10) \\ &= \pi_t + \tilde{b}_1\left(\pi_t - \pi^*\right) + \tilde{b}_2 y_t, \qquad (6.11) \end{aligned}$$

where

$$\tilde{b}_1 = \frac{1-c}{\beta_2\alpha_1} \text{ and } \tilde{b}_2 = \frac{1-c+\beta_1}{\beta_2}. \tag{6.12}$$

The real repo rate is increasing in the excess of the two-year inflation forecast over the inflation target, (6.10), or in the excess of current inflation over the inflation target, (6.11), in addition to being increasing in output. We see that $\lambda = 0$ ($c = 0$) results in $\tilde{b}_1 = b_1$ and $\tilde{b}_2 = b_2$ in the single-goal reaction function (2.13). With a positive weight on output stabilization, the coefficients in the reaction function are smaller.

Output and inflation will in equilibrium, by (6.4), (6.5) and (6.11), obey

$$\begin{aligned} y_{t+1} &= -\frac{1-c}{\alpha_1}(\pi_t - \pi^*) - (1-c)\, y_t + \eta_{t+1}, \\ \pi_{t+1} - \pi_t &= \alpha_1 y_t + \epsilon_{t+1} \\ &= -(1-c)(\pi_{t-1} - \pi^*) - \alpha_1 (1-c)\, y_{t-1} + \alpha_1 \eta_t + \epsilon_{t+1}. \end{aligned}$$

We see that both output and inflation are mean-reverting, output towards the natural output level and inflation towards the inflation target.

In summary, some weight on output stabilization motivates a gradual adjustment of the two-year inflation forecast towards the long-run inflation target. The two-year inflation forecast is brought closer to the long-run inflation target than the predetermined one-year inflation target, but not all the way, in order to reduce output variability. The less weight on output stabilization, the faster the adjustment towards the long-run inflation target.[24]

This case can be interpreted as a *variable short-run* target for the two-year inflation rate,

$\pi^* + c\left(\pi_{t+1|t} - \pi^*\right)$, that deviates from the long–run inflation target π^* in proportion to the one-year inflation forecast's deviation from the long-run target.

Thus, a weight on output stabilization makes inflation targeting more complicated, but not overly so. The central bank has to explain that the inflation forecast is only gradually adjusted towards the long-run target. The outside monitoring of the central bank needs to be somewhat more sophisticated. Inflation targeting remains intuitive and transparent.[25]

7 The role of bands

Most inflation targeting regimes have an explicit band for inflation, either in the form of a target band without an explicit inflation point target, or in the form of a band around an explicit inflation (point) target. These bands can potentially be interpreted in several ways. First, one may ask whether inflation is supposed to remain within the band all the time, or most of the time. The announced bands are typically 2 percentage points wide, which together with the imperfect control over inflation makes it rather likely that inflation will sometimes move outside the bands. It may then be more transparent to the public if the central bank explicitly acknowledges this, for instance by announcing that it expects to keep inflation within the band x per cent of the time. Apparently, inflation targeting central banks have so far shunned such precise statements. From an analytical viewpoint it seems natural to interpret the bands as a confidence interval, proportional to the unconditional standard deviation of inflation, the square root of the

[24] Note that an instrument-smoothing objective would similarly make the inflation forecast temporarily deviate from the inflation target in order to reduce the necessary instrument change, cf. Goodhart (1996) for a recent discussion. Stevens and Debelle (1995) conduct very interesting simulations on an empirical model of the Australian economy, similar to the model (2.1) - (2.3) with a loss function like (6.1) where interest rate smoothing is added.

[25] Since the optimal policy with positive weight on output stabilization is thus a steady leaning towards the long-run inflation target, it is very different from the so-called opportunistic approach to disinflation discussed in Orphanides and Wilcox (1996) and Rudebusch (1996).

sum of the variance of the conditional expectation of inflation and the variance of the inflation forecast errors.

In addition to bands for realized inflation, we can also consider potential bands for inflation *forecasts*, for conditional expectations of inflation. Bands for inflation forecasts would then be proportional to the unconditional standard deviation of inflation forecasts.

7.1 A single goal

Consider first the situation when inflation targeting is interpreted as a single goal, in the sense that only inflation enters the central bank's loss function. The band for realized inflation is then proportional to the standard deviation of possible deviations of realized inflation from the inflation target, due to uncertainty about, and imperfect control of, future inflation. It indicates an anticipated 'unavoidable' variability of inflation. The bandwidth is proportional to the unconditional standard deviation of the sum of control and forecast errors, but *not* deviations of the inflation forecast (the intermediate target) from the inflation target, since the inflation forecast should always equal the inflation target with a single goal. In terms of the model, the bandwidth would be proportional to $\sqrt{2\sigma_\epsilon^2 + \sigma_\eta^2 + \sigma_\theta^2}$, cf. (2.15).

With a single goal there is hence room for a very narrow band for the inflation forecast at most; in the stylized model above there is a zero band for the inflation forecast.

7.2 Multiple goals

With multiple goals, conscious deviations of the inflation forecast from the inflation target occurs. The band for realized inflation then incorporates the unconditional variance of the deviation of inflation forecasts (short-run inflation targets) from the inflation target (the long-run inflation target), in addition to the variance of forecast errors.

There is hence an implicit band for the inflation forecast, in proportion to the unconditional standard deviation of the inflation forecast, which will be increasing in the weight on additional goals. In the above model, that unconditional standard deviation will be increasing in λ, the relative weight on output stabilization, but also depend on the other parameters of the problem.

A wide band could then potentially indicate that the central bank has a relatively high λ and hence a significant output stabilization goal. A narrow band could indicate a commitment to a low or even zero λ, cf. the discussion in Svensson (1996c).

7.3 Accountability

The band for realized inflation can be used to increase the accountability of the central bank, and the central bank may be subject to sanctions if realized inflation moves outside the band. The most explicit example is New Zealand, where the Governor may then be relieved from his post. As discussed by Walsh (1993), this is an optimal arrangement even though inflation is also subject to disturbances outside the control of the central bank, if only realized inflation and not the actions of the central bank can be observed and verified. The optimal bandwidth can then be chosen so as to achieve the optimal trade-off between type I and type II errors (the Governor is fired (because of unanticipated and unobservable

disturbances) even though he/she has chosen the (ex ante) appropriate policy, or the Governor is retained even though he/she has chosen an (ex ante) inappropriate policy).

If the central bank's inflation forecast can be observed and verified, it is better to make sanctions conditional upon a band for the inflation forecast rather than realized inflation, since then the noise (and injustice) from unobserved disturbances is eliminated. It remains to be seen whether a central bank's inflation forecasts can be made so observable and verifiable as to allow sanctions to be conditional on forecasts rather than outcomes. If the amount of private information of the central bank is substantial, this may require rather sophisticated incentive schemes in order to induce the central bank to reveal the necessary information, cf. Persson and Tabellini (1993) and Walsh (1995a). Before these issues are resolved, I believe it is best to base possible sanctions on realized inflation, as in New Zealand, rather than on inflation forecasts.

8 Target rules versus instrument rules

Setting the instrument to make the inflation forecast equal to the inflation target is an example of a *target rule* which, if applied by the monetary authority, results in an endogenous optimal reaction function expressing the instrument as a function of the available relevant information. This is different from an *instrument rule* that directly specifies the reaction function for the instrument in terms of current information. In the literature, there are two prominent instrument rules, the McCallum rule for the monetary base, proposed by McCallum in several papers, for instance McCallum (1990),[26] and the Taylor rule for the federal funds rate, in Taylor (1993, 1996a,b).

Setting the instrument so as to fulfill the target rules (2.9) or (6.8) results in endogenous instrument rules, (2.13) or (6.11). The above target rules depend only on the parameters in the Phillips curve and the central bank's loss function (the single-goal target rule (2.9) depends only on the long-run inflation target). In contrast, the instrument rules also depend on the aggregate demand function. Therefore, the target rules are less complex and more robust than the instrument rules. In the real world, much different information is relevant to forecast inflation; the instrument rule is in principle a complicated function of all such information, not just a few macro variables.

Even though I believe instrument rules like the McCallum and Taylor rules are important advances in the theory of monetary policy, I consider a commitment to a target rule to be a more advantageous arrangement than a commitment to an instrument rule. A target rule focuses on the essential, that is, to achieve the goal, and allows more flexibility in finding the corresponding reaction function. More specifically, with new information about structural relationships, such as changes in exogenous variables, a target rule implies automatic revisions of the reaction function. A commitment to an explicit instrument rule either requires more confidence in the structural model and its stability, or frequent revision that may be difficult to motivate. Target rules are inherently more stable than instrument rules, and easier to identify, motivate and verify.

[26] Although Goodhart (1994) questions whether the monetary base is under sufficient control of the central bank to qualify as an instrument.

9 Conclusions

Although inflation targeting has several general advantages, it faces some potentially very serious problems with regard to both its implementation by the monetary authority and its monitoring by the public. Implementation is difficult due to the imperfect control of inflation. Monitoring is difficult since inflation reacts to changes in the monetary policy instrument with long and variable lags, and since inflation is affected by other factors than monetary policy. This paper argues that there is a straightforward solution to these problems, namely that inflation targeting can be implemented as inflation forecast targeting, in the sense that the monetary authority's inflation forecast is treated as an explicit intermediate target.

The monetary authority can then implement inflation targeting by simply setting the instrument such that its inflation forecast for a horizon corresponding to the control lag equals the inflation target. Ex post realized inflation will deviate from the inflation forecast due to disturbances that occur within the control lag, but these are beyond the control of the monetary authority. The best the monetary authority can do is to get its inflation forecast equal to the inflation target, which will minimize the squared deviations of realized inflation from the inflation target. In order to avoid the problems of instability, multiplicity and even non-existence of equilibria that Woodford (1994) has emphasized, the intermediate target should be the monetary authority's own forecast (based on the fundamental determinants of inflation, the current state of the economy, and the instrument) and not a consensus forecast of outside observers. In particular, the central bank must have a view of how the forecast is affected by the current instrument.

The public can monitor and evaluate inflation targeting by observing and scrutinizing the monetary authority's inflation forecast, in the favorable situation when the monetary authority reveals the details of its forecast. The public can also use inflation forecasts of other forecasters' forecasts for this purpose, especially if the monetary authority keeps its forecast secret to some extent. A healthy competition is likely to arise between the monetary authority and outside professional or academic forecasters with regard to the quality of the analysis and forecasts. Although the construction of inflation forecasts is difficult and demanding, the monetary policy conclusions for a given forecast follow simple and intuitive principles: If the forecast is on target, monetary policy is appropriate. If the forecast is above (below) the target, monetary policy should be tightened (eased). This should improve monetary authority communication with the public, the public's understanding of monetary policy, and the predictability of monetary policy.

The inflation targeting framework is especially straightforward to implement and monitor when it is interpreted as involving a single goal only. With additional goals, like stabilizing output or employment, the inflation targeting framework becomes somewhat more complex, but still very intuitive. It can then be interpreted as having a constant long-run inflation target equal to the announced constant inflation target, and a flexible short-run inflation target which is a weighted average of the long-run inflation target and the predetermined one-year inflation forecast. Put differently, a desire to reduce output variability implies that the inflation forecast adjusted gradually towards the long-run target, at a slower rate the more weight is put on output stabilization. Thus both the implementation and monitoring of inflation targeting becomes a bit more complex, but

not overly so.

Setting the instrument to make the inflation forecast equal to the inflation target is an example of a target rule, which is different from an instrument rule that directly specifies the reaction function for the instrument. I believe a target rule is a more advantageous arrangement, since it focuses on the essential, that is, to achieve the target, is inherently less complex and more stable, and is easier to identify, motivate and verify.

However, it might be argued that the lack of knowledge, and resulting disagreement, about the appropriate macroeconomic model not only make instrument rules inferior to target rules, but that they may be so substantial as to make both the implementation and monitoring of the target rule proposed here too difficult. Imperfect knowledge about the model certainly poses a general problem for monetary policy. But the inflation targeting framework outlined above is likely to provide very strong incentives for the monetary authority to improve its understanding of the economy and its control of inflation, especially if the monetary authority chooses or is obliged to reveal its model and analysis in detail to the public.[27]

Generally I find it unlikely that monetary authorities have much private information, relative to sophisticated outside observers, about the state of the economy and the behavior of the economy, but that their private information mostly concerns their own implicit goals and their corresponding plans for the future instrument. This is consistent with an important role for outside observers in detecting and preventing monetary authority deviations from explicit goals. However, to the extent that monetary authorities do have private information about the state and behavior of the economy, the issue of their incentives to truthfully reveal their information to the public becomes most important. There seems to be room for considerable future research both on the extent of such private information, and on possible incentive schemes to induce monetary authorities to reveal the truth.[28]

Finally, inflation targeting implicitly or explicitly allows base drift of the price level. The price level then becomes non-stationary and integrated of order one, with price level uncertainty increasing in the forecasting horizon. Price level targeting, which makes the price level stationary and reduces long-term price level uncertainty, has received increased attention in the recent literature, cf. Bank of Canada (1994). Once central banks have learned to successfully target inflation, more ambitious price level targeting may be both a realistic and desirable alternative. Indeed, in Svensson (1996d) it is demonstrated that price level targeting, counter to conventional wisdom, may actually *reduce* rather than increase *short*-term inflation variability.

A Period-by-period optimization

The problem to choose $\{i_\tau\}_{\tau=t}^{\infty}$ so as to minimize

$$\mathrm{E}_t \frac{1}{2} \sum_{\tau=t}^{\infty} \delta^{\tau-t} (\pi_\tau - \pi^*)^2 , \tag{A.1}$$

[27] See Svensson (1996b) for a discussion of inflation targeting under model uncertainty.

[28] See Romer and Romer (1996a) for an example of the former, and Persson and Tabellini (1993) and Walsh (1995a) for examples of the latter.

where each i_τ depends on information available in period τ, can be written as a sequence of one-period problems

$$\min_{i_t} \mathrm{E}_t \frac{1}{2}\delta^2 (\pi_{t+2} - \pi^*)^2 + \mathrm{E}_t \sum_{\tau=t+1}^{\infty} \delta^{\tau-t} \min_{i_\tau} \mathrm{E}_\tau \frac{1}{2} (\pi_{\tau+2} - \pi^*)^2, \tag{A.2}$$

since $\pi_{\tau+2}$ according to (2.12) can be controlled by i_τ and is not affected by $i_{\tau+1}$, $i_{\tau+2}$,... This can for instance be seen from the first-order condition for the problem

$$\min_{i_t} \frac{1}{2} \mathrm{E}_t \sum_{\tau=t}^{\infty} \delta^{\tau-t} (\pi_\tau - \pi^*)^2,$$

which is

$$\mathrm{E}_t \sum_{\tau=t}^{\infty} \delta^{\tau-t} (\pi_\tau - \pi^*) \frac{\partial \pi_\tau}{\partial i_t} = \sum_{\tau=t+2}^{\infty} \delta^{\tau-t} \left(\pi_{\tau|t} - \pi^*\right) \frac{\partial \pi_\tau}{\partial i_t} = 0, \tag{A.3}$$

where I have used that $\frac{\partial \pi_\tau}{\partial i_t}$ due to the linearity of the model will be constant. Due to (2.12) i_t can be chosen such that

$$\pi_{t+2|t} - \pi^* = 0.$$

Similarly, i_τ, $\tau = t+1, t+2, ...$, can be chosen such that

$$\pi_{\tau+2|\tau} - \pi^* = 0. \tag{A.4}$$

Due to the law of iterated expectations it follows that

$$\pi_{\tau|t} - \pi^* = 0, \quad \tau = t+3, \ t+4, ...$$

and the first-order condition (A.3) can be fulfilled with each term in the sum equal to zero. It is clear that this must correspond to a global minimum of the problem. The one-period problem

$$\min_{i_\tau} \delta^2 \mathrm{E}_\tau \frac{1}{2} (\pi_{\tau+2} - \pi^*)^2$$

results in (A.4), so a sequence of one-period problems as in (A.2) will result in the global minimum.

B Output stabilization

B.1 One-year control lag for inflation

In order to derive the first-order condition (6.6) it is practical to first study the simpler problem

$$V(\pi_t) = \min_{y_t} \left\{ \frac{1}{2} \left[(\pi_t - \pi^*)^2 + \lambda y_t^2 \right] + \delta \mathrm{E}_t V(\pi_{t+1}) \right\} \tag{B.1}$$

subject to

$$\pi_{t+1} = \pi_t + \alpha_1 y_t + \epsilon_{t+1}, \tag{B.2}$$

where output y_t is regarded as a control variable.

The indirect loss function $V(\pi_t)$ will be quadratic,

$$V(\pi_t) = k_0 + \frac{1}{2}k\left(\pi_t - \pi^*\right)^2, \tag{B.3}$$

where the coefficients k_0 and k remain to be determined. The first-order condition is

$$\lambda y_t + \delta \mathrm{E}_t V_\pi(\pi_{t+1})\alpha_1 = \lambda y_t + \delta\alpha_1 k\left(\pi_{t+1|t} - \pi^*\right) = 0,$$

where I have used (B.3). This can be written

$$\pi_{t+1|t} - \pi^* = -\frac{\lambda}{\delta\alpha_1 k} y_t. \tag{B.4}$$

The decision rule for output fulfills

$$\begin{aligned} y_t &= -\frac{\delta\alpha_1 k}{\lambda}\left(\pi_{t+1|t} - \pi^*\right) \\ &= -\frac{\delta\alpha_1 k}{\lambda + \delta\alpha_1^2 k}\left(\pi_t - \pi^*\right), \end{aligned}$$

where I have used that by (B.2)

$$\pi_{t+1|t} = \pi_t + \alpha_1 y_t.$$

Then the equilibrium inflation forecast fulfills

$$\pi_{t+1|t} = \pi_t + \alpha_1 y_t = \pi^* + \left(1 - \frac{\delta\alpha_1^2 k}{\lambda + \delta\alpha_1^2 k}\right)\left(\pi_t - \pi^*\right) = \pi^* + \frac{\lambda}{\lambda + \delta\alpha_1^2 k}\left(\pi_t - \pi^*\right). \tag{B.5}$$

In order to identify k I exploit the envelope theorem for (B.1) and (B.3) and use (B.5), which gives

$$V_\pi(\pi_t) = k\left(\pi_t - \pi^*\right) = \left(\pi_t - \pi^*\right) + \delta k\left(\pi_{t+1|t} - \pi^*\right) = \left(1 + \frac{\delta\lambda k}{\lambda + \delta\alpha_1^2 k}\right)\left(\pi_t - \pi^*\right).$$

Identification of the coefficient for $\pi_t - \pi^*$ gives

$$k = 1 + \frac{\delta\lambda k}{\lambda + \delta\alpha_1^2 k}.$$

The right-hand side is equal to unity for $k = 0$ and increases towards $1 + \frac{\lambda}{\alpha_1^2}$ for $k \to \infty$. We realize that there is a unique positive solution which fulfills $k \geq 1$. It can be solved analytically:

$$k^2 - \left(1 - \frac{\lambda(1-\delta)}{\delta\alpha_1^2}\right)k - \frac{\lambda}{\delta\alpha_1^2} = 0,$$

$$\begin{aligned} k &= \frac{1}{2}\left(1 - \frac{\lambda(1-\delta)}{\delta\alpha_1^2} + \sqrt{\left(1 - \frac{\lambda(1-\delta)}{\delta\alpha_1^2}\right)^2 + \frac{4\lambda}{\delta\alpha_1^2}}\right) \\ &= \frac{1}{2}\left(1 - \frac{\lambda(1-\delta)}{\delta\alpha_1^2} + \sqrt{\left(1 - \frac{\lambda(1-\delta)}{\delta\alpha_1^2}\right)^2 + \frac{4\lambda(1-\delta)}{\delta\alpha_1^2} + \frac{4\lambda}{\alpha_1^2}}\right) \\ &= \frac{1}{2}\left(1 - \frac{\lambda(1-\delta)}{\delta\alpha_1^2} + \sqrt{\left(1 + \frac{\lambda(1-\delta)}{\delta\alpha_1^2}\right)^2 + \frac{4\lambda}{\alpha_1^2}}\right) \geq 1. \end{aligned} \tag{B.6}$$

B.2 Two-year control lag for inflation

After these preliminaries, consider the problem

$$\min_{i_t} \mathrm{E}_t \sum_{\tau=0}^{\infty} \delta^\tau L(\pi_{t+\tau}, y_{t+\tau})$$

subject to

$$\begin{aligned} L(\pi_t, y_t) &= \frac{1}{2}\left[(\pi_t - \pi^*)^2 + \lambda y_t^2\right] \\ \pi_{t+1} &= \pi_t + \alpha_1 y_t + \epsilon_t \\ y_{t+1} &= \beta_1 y_t - \beta_2(i_t - \pi_t) + \eta_{t+1}. \end{aligned}$$

We realize that this can be formulated as

$$V(\pi_{t+1|t}) = \min_{y_{t+1|t}} \left\{ \frac{1}{2}\left[\left(\pi_{t+1|t} - \pi^*\right)^2 + \lambda y_{t+1|t}^2\right] + \delta \mathrm{E}_t V(\pi_{t+2|t+1}) \right\}$$

subject to

$$\begin{aligned} \pi_{t+2|t+1} &= \pi_{t+1} + \alpha_1 y_{t+1} \\ &= \pi_{t+1|t} + \alpha_1 y_{t+1|t} + \left(\epsilon_{t+1} + \alpha_1 \eta_{t+1}\right), \end{aligned}$$

where $y_{t+1|t}$ is regarded as the control, and where the optimal repo rate can be inferred from

$$i_t - \pi_t = -\frac{1}{\beta_2} y_{t+1|t} + \frac{\beta_1}{\beta_2} y_t.$$

This problem is analogous to the problem (B.1) subject to (B.2). Thus, in analogy with (B.4), the first-order condition can be written

$$\pi_{t+2|t} - \pi^* = -\frac{\lambda}{\delta \alpha_1 k} y_{t+1|t}, \tag{B.7}$$

and the reaction function will fulfill

$$\begin{aligned} i_t - \pi_t &= -\frac{1}{\beta_2} y_{t+1|t} + \frac{\beta_1}{\beta_2} y_t \\ &= \frac{\delta \alpha_1 k}{\lambda \beta_2}\left(\pi_{t+2|t} - \pi^*\right) + \frac{\beta_1}{\beta_2} y_t \\ &= \frac{\delta \alpha_1 k}{\lambda \beta_2}\left[\pi_t - \pi^* + \alpha_1 (1 + \beta_1) y_t - \alpha_1 \beta_2 (i_t - \pi_t)\right] + \frac{\beta_1}{\beta_2} y_t \\ &= \frac{\delta \alpha_1 k}{\beta_2 (\lambda + \delta \alpha_1^2 k)} (\pi_t - \pi^*) + \frac{1}{\beta_2}\left(\frac{\delta \alpha_1^2 k}{\lambda + \delta \alpha_1^2 k} + \beta_1\right) y_t, \end{aligned}$$

where I have used

$$\pi_{t+2|t} = \pi_t + \alpha_1(1 + \beta_1) y_t - \alpha_1 \beta_2 (i_t - \pi_t),$$

and where k will obey (B.6).

Since by (6.4) we have

$$y_{t+1|t} = \frac{1}{\alpha_1}\left(\pi_{t+2|t} - \pi_{t+1|t}\right),$$

we can eliminate $y_{t+1|t}$ from (B.7) and get, after some algebra,

$$\pi_{t+2|t} = \pi^* + c\left(\pi_{t+1|t} - \pi^*\right), \tag{B.8}$$

where

$$0 \leq c = \frac{\lambda}{\lambda + \delta\alpha_1^2 k} < 1. \tag{B.9}$$

The coefficient $\frac{\lambda}{\delta\alpha k}$ in (B.7) and c in (B.9) will be (i) increasing in λ and (ii) decreasing in α_1. To show (i), consider

$$z = \frac{k}{\lambda} = \frac{1}{2}\left[\frac{1}{\lambda} - \frac{1-\delta}{\delta\alpha_1^2} + \sqrt{\left(\frac{1}{\lambda} + \frac{1-\delta}{\delta\alpha_1^2}\right)^2 + \frac{4}{\lambda\alpha_1^2}}\right] = \frac{1}{2}\left[w - A + \sqrt{(w+A)^2 + 4ABw}\right],$$

where

$$w = \frac{1}{\lambda},\ A = \frac{1-\delta}{\delta\alpha_1^2} > 0,\ B = \frac{\delta}{1-\delta} > 0.$$

It is straightforward to show that $\frac{\partial z}{\partial w} > 0$, hence that $\frac{\partial(k/\lambda)}{\partial\lambda} < 0$, and $\frac{\partial(\lambda/k)}{\partial\lambda} > 0$. To show (ii), consider

$$v = \alpha_1 k = \frac{1}{2}\left[\alpha_1 - \frac{C}{\alpha_1} + \sqrt{\left(\alpha_1 + \frac{C}{\alpha_1}\right)^2 + 4\lambda}\right],$$

where

$$C = \frac{\lambda(1-\delta)}{\delta} > 0.$$

It is sufficient to show that $\frac{\partial v}{\partial\alpha_1} > 0$. Thus,

$$\begin{aligned}
2\frac{\partial v}{\partial\alpha_1} &= 1 + \frac{C}{\alpha_1^2} + \frac{2\left(1 + \frac{C}{\alpha_1^2}\right)\alpha_1\left(1 - \frac{C}{\alpha_1^2}\right)}{2\sqrt{\left(\alpha_1 + \frac{C}{\alpha_1}\right)^2 + 4\lambda}} \\
&= \left(1 + \frac{C}{\alpha_1^2}\right)\left(1 + \frac{\alpha_1 - \frac{C}{\alpha_1}}{\sqrt{\left(\alpha_1 + \frac{C}{\alpha_1}\right)^2 + 4\lambda}}\right) \\
&= \left(1 + \frac{C}{\alpha_1^2}\right)\frac{\sqrt{\left(\alpha_1 + \frac{C}{\alpha_1}\right)^2 + 4\lambda} + \left(\alpha_1 - \frac{C}{\alpha_1}\right)}{\sqrt{\left(\alpha_1 + \frac{C}{\alpha_1}\right)^2 + 4\lambda}} > 0.
\end{aligned}$$

It follows that c increases monotonically from zero towards one when λ goes from zero to infinity.

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